A Programmatic Approach to On Condition Maintenance

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Background – Where we started

- Purchased 80 COTS Honeywell Model 8500C Balancer/Analyzer, as existing equipment was not supportable (1.56 M, FY 96)
- Engine Front Frame Cracking #1 Safety Issue
  - Vibration due to poor RT&B causing cracking
  - Excessive #1 Bearing oil leakage, ingested by engine, caused in-flight emergency engine shut downs
  - Costs squadron man-hours and engine replacement
- Premature structural and hinge point failures experienced
- New RT&B procedure successfully developed to eliminate engine front frame cracking
- DCC-81 Modified rotor blades (105K, FY 97)
- Elimination of Whirl Tower saved $5M Annually

Drive to utilize equipment to its capacity

Phase I

Getting Started and Setting the Foundation

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Initial Testing and Instrumentation

- COTS equipment could collect vibration data
- COTS software needed to automate the O level aspect of the analysis
- Develop the frequency models of the engine and drive train
- Optimize sensor locations through surveys and initial testing
- Collect data that can help establish good vibration limits
- Validate the system approach before fleet implementation

Data Analysis Software

- **Merely collecting data without having tools to drive real world interpretation will lead to failure**
- **Limits and data collection sequences must be modifiable by the Navy Engineering Staff**
  - **Older Vibration Equipment required the vendor to modify software any time a change was needed**
- **Software should keep it simple for the end user**
- **Maintenance manuals should interface with analysis system**

Analysis Software is Key

System Training

- Teach the theory, not just the how
- Instructional and practical/hands-on methods required
- Share results
- Empower the user to be a part of the system developments/enhancements
- Technical representatives at the sites are key to success

Communicate system benefits through training

Phase II

Periodic Vibration Checks

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Slow methodical implementation

- 100 hour/phase checks increased knowledge
- Gained momentum as troubleshooting tool
- Maintenance time decreased
- Data review identified issues we never could have seen with previous test methods
- Allowed us to evaluate effectiveness before spending a lot of money
- Avoids false removals / A799 rates
- Able to grant high time component life extensions
- Fleet demand drove follow-on buy of 30 more 8500C units (780K, FY 98)

Early steps realized significant savings

Five Significant Case Examples

- High Speed Shaft Resonance
- High Speed Shaft Adapter Imbalance
- Main Electrical Generator failures
- Service life extensions for aft transmissions
- Excessive engine vibrations

High Speed Shaft Resonance

Problem

- Damaged torque sensors
- Erroneous torque readings

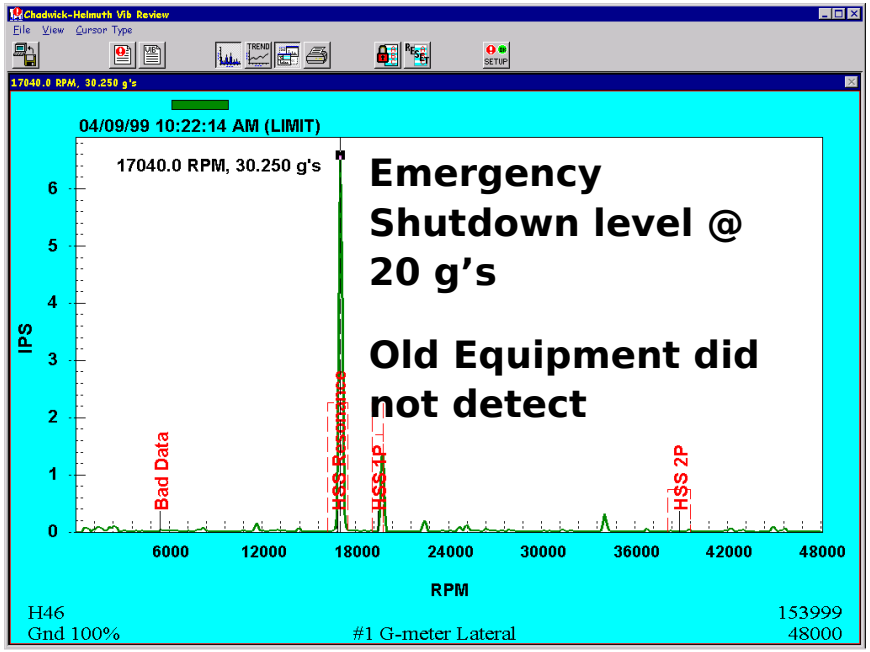
Findings

- Spline wear allowing resonance in HSS
- HSS resonance undetected with previous equipment
- Pilots troubleshooting by throttling the engine back and causing resonance
- Spectral analysis equipment can detect resonance

Resolution

- Inspection of spline wear implemented
- Check for resonance with use of narrowband equipment when erratic torque readings reported
- Pilots instructed to operate at 100% Nf/Nr

Damaged Torque Sensors



High Speed Shaft Adapter Imbalance

Problem

- Increase in shaft removal & rejection
- Seals failing
- Engines and transmissions were being removed

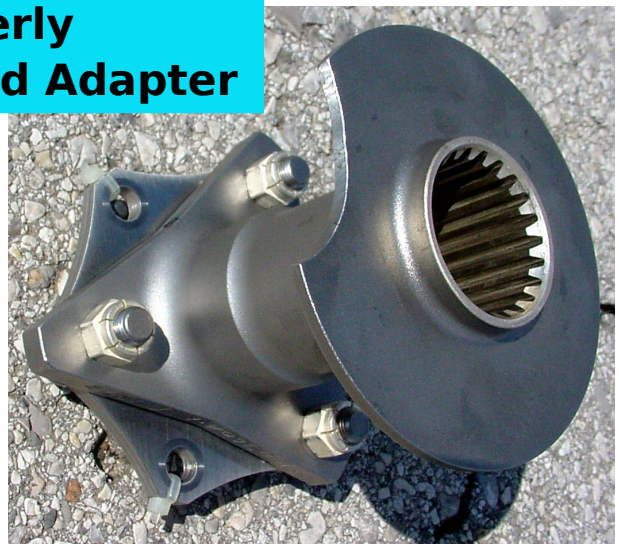
Findings

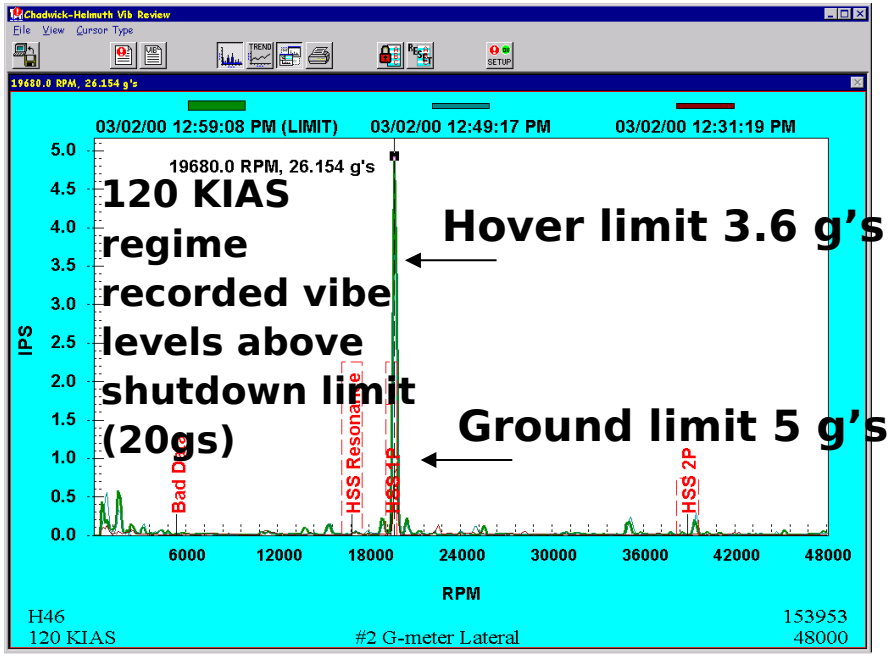
- Periodic vibration checks expanded to in flight regimes revealed HSS levels as high as 26 g's
- Balancing procedures at vendor and depot facilities found to be inadequate

Resolution

- Balance machines updated and match set balancing implemented

Improperly Balanced Adapter





Electrical Generator Failures

Problem

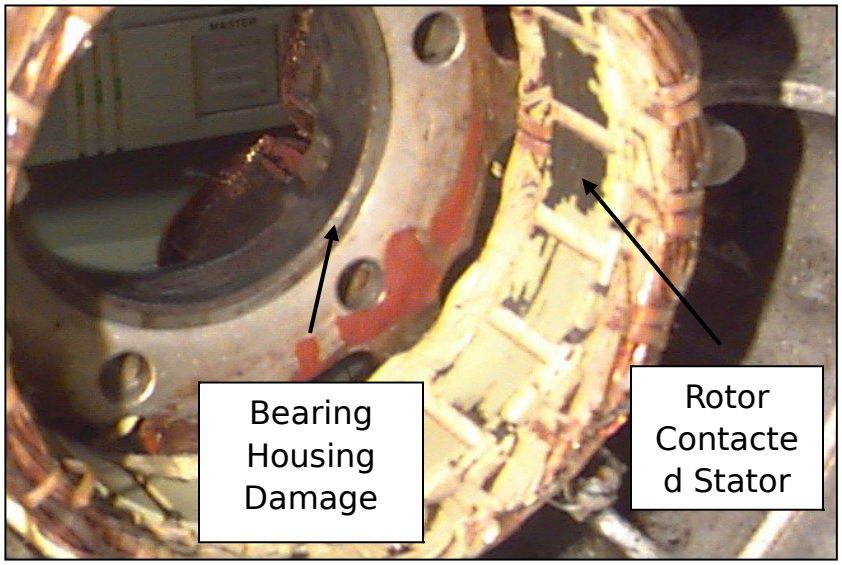
- Catastrophic generator failures
- Failures causing in-flight hazards & emergency shutdown

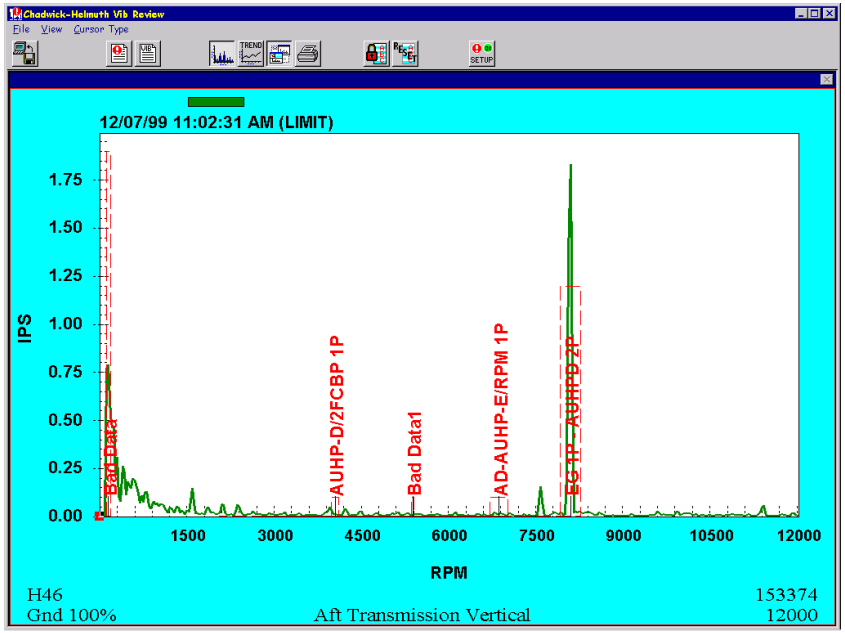
Findings

- Change in scheduled maintenance allowing generators to run to failure

Resolution

- New vibration check procedure identifies degraded generators before catastrophic failure
- Scheduled overhaul replaced with vibration check (on-condition)
- Saves ~900K per year





AFT Transmission Life Extensions

Problem

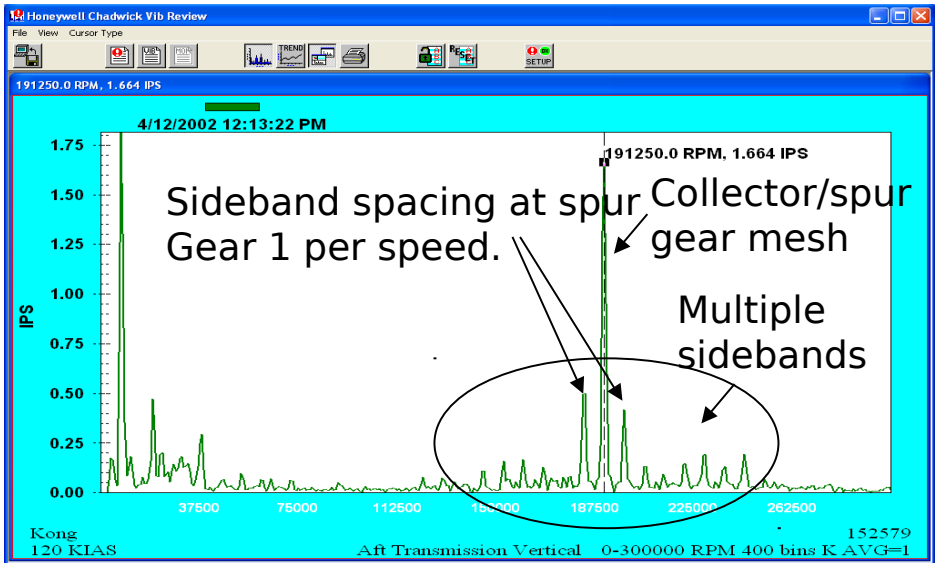
- **High time of Aft Xmsn is 900 hours**
- **Life extensions granted without data**
- **Untimely failures resulted**

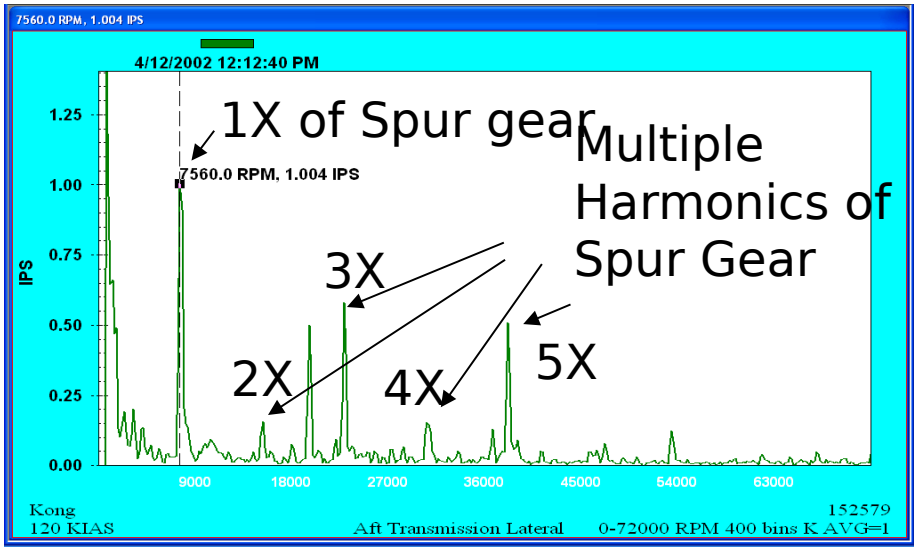
Findings

- **Failures can be detected by vibration analysis**

Resolution

- **Mandatory submittal of vibration data required for life extensions**
- **If able to eliminate resonance the Xmsn may be able to extend to 1800 hours**





Excessive Engine Vibrations

Problem

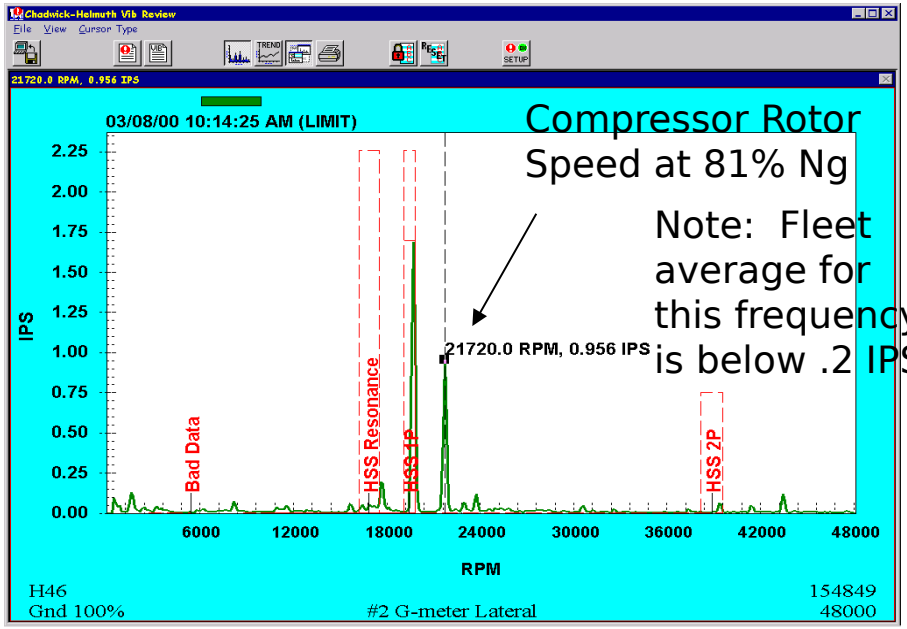
- **Loud audible howl on newly overhauled engine**

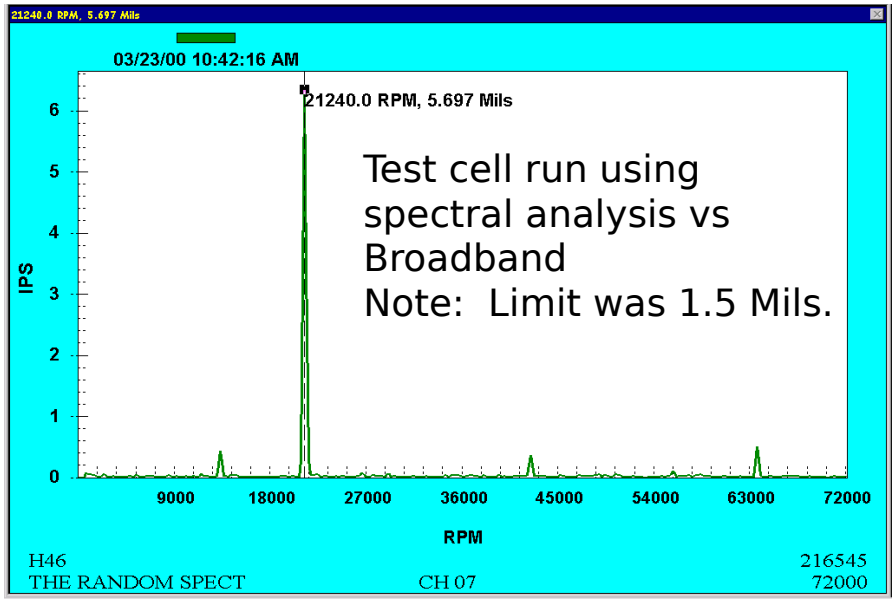
Findings

- **All test cell runs passed**
- **Mils Broadband was acceptance criteria**
- **Mobile test cell failed to identify problem**
- **Poorly balanced compressor rotor caused damage to 8th, 9th, and 10th stages of the rotor**

Resolution

- **3 spectral analyzer fielded in test cells for data collection**





Phase III

Justification for Hardwiring of Aircraft

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Eng Drive Shaft Catastrophic Failure

Problem

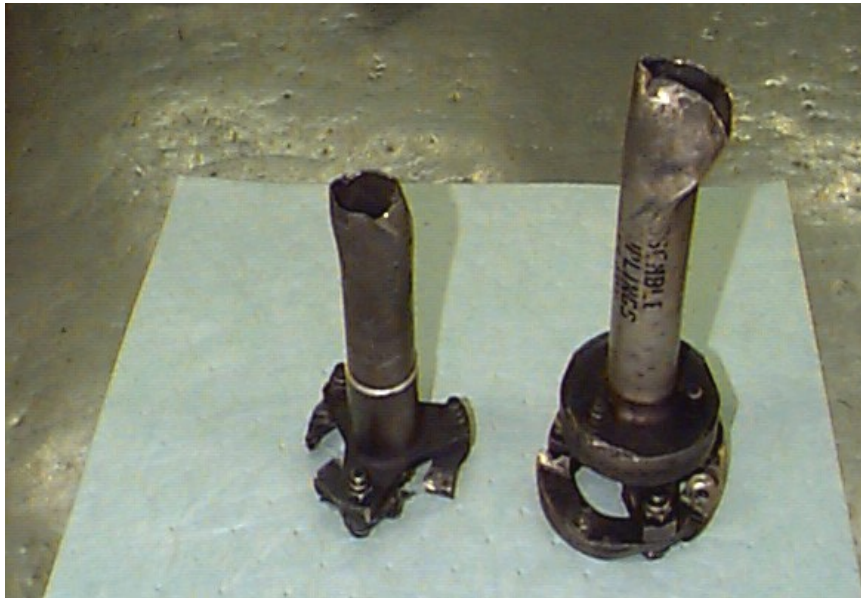
- Test of #1 & #2 Engine Drive Shafts indicated misalignment on Engine #1

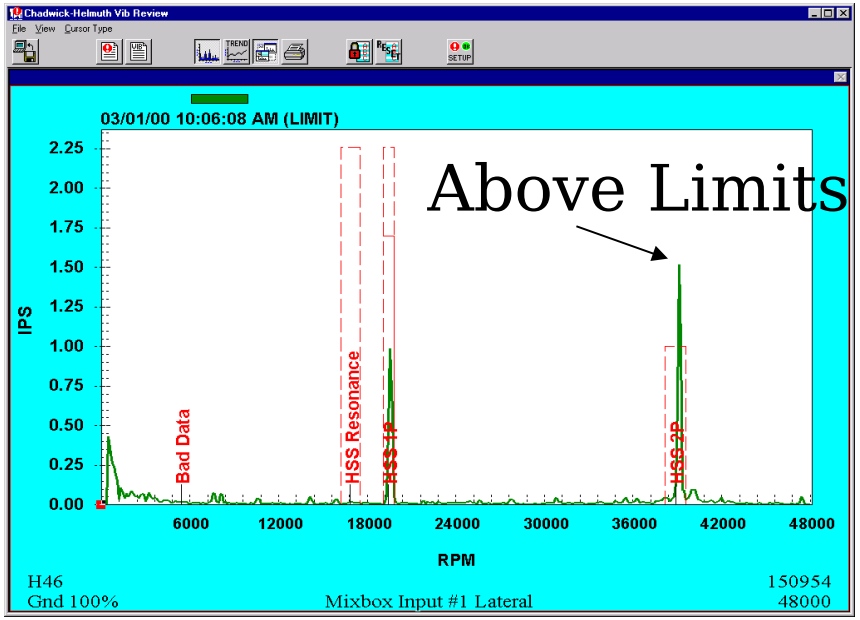
Findings

- Maintenance performed and aircraft released to serviceability
- #2 Engine Drive shaft failed catastrophically in flight
- Equipment installed incorrectly
- Maintenance performed on incorrect shaft

Resolution

- Human error allowed component to fly to failure
- Hardwiring would have prevented this error





AFC 433 Part 12

- Purchased kits to install sensors and wiring in approximately 180 aircraft (1.2M, FY 00)
- Prepares aircraft for onboard vibration system expansion
- Solved fleet driven complaints about SE wear and tear

Phase IV

Test Cell Expansion

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Initial Testing and Implementation

- **Began initial data collection using 3 8500C spectrum analyzers in late 1999**
  - **2 at NADEP Cherry Point**
  - **1 at MALS-29/26**
- **Noted significant gains by progressing towards spectral analysis**
  - **Provided means to isolate specific frequency(s) yielding greatest amount of vibration**
  - **Significant unbalance conditions noted on main rotating components**
    - New balance machines and procedures incorporated (350K)
- **COTS spectrum analyzers (VXP) fielded in early 2001 (235K, FY 01)**
- **Spectral analysis now used on all test cells to accept/reject engines**

Older Vibration System Costs

- **Vibration data collected by Broadband system had falsely led fleet to reject multiple Power Turbine assemblies due to excessive vibration**
  - **GE proposed an expensive redesign of the PT bearing/housing as a viable solution**
- **COTS vibration analyzers uncovered the dominant frequency causing the vibration, which was the Gas Generator Turbine**
  - **Immediately avoided countless PT overhauls (fleet wide)**
  - **GE ceased bearing redesign effort**
  - **Yearly savings realized, using spectral analysis, due to fault isolation capabilities**
    - PT Rotor Cost: $47,757/unit
    - PT Assembly Cost: $99,264/assembly

Substantial Finding – Impending Bearing Failure

Problem

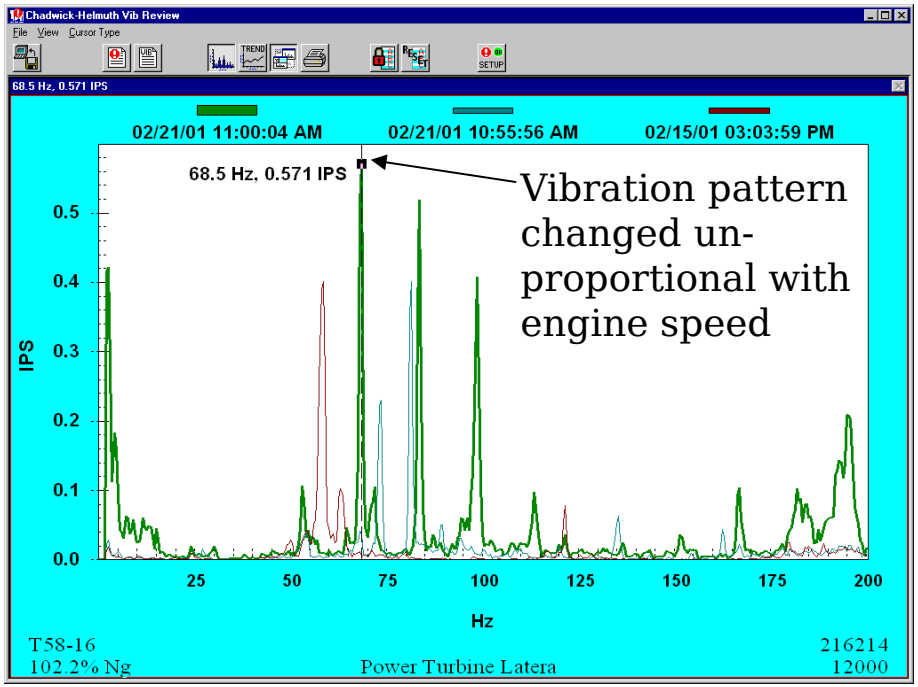
- Engine passed test cell based upon Broadband vibration test
- Rejected on-wing due to audible howling

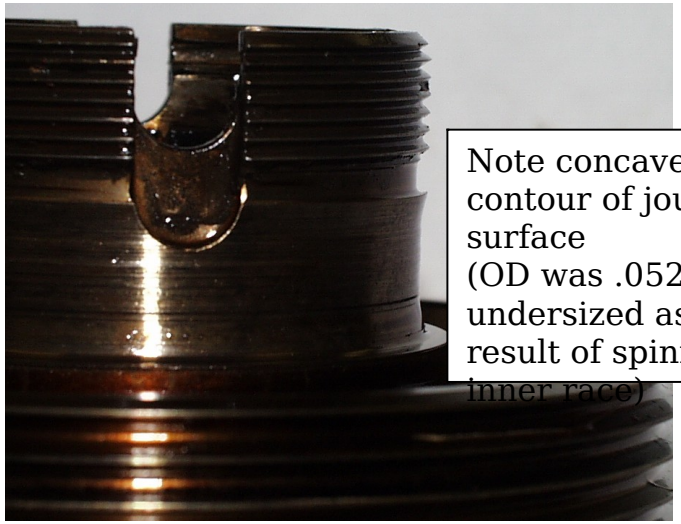
Findings

- Spectral analysis indicated Gas Generator Turbine as the problem area
- Troubleshooting with the spectral analysis concluded to non-synchronous behavior, indicating spinning bearing race
- Large fragments found upon teardown
- Test cell Broadband equipment not properly configured

Resolution

- Early detection of bearing wear possible with spectral analysis, avoiding potential catastrophic failure on-wing

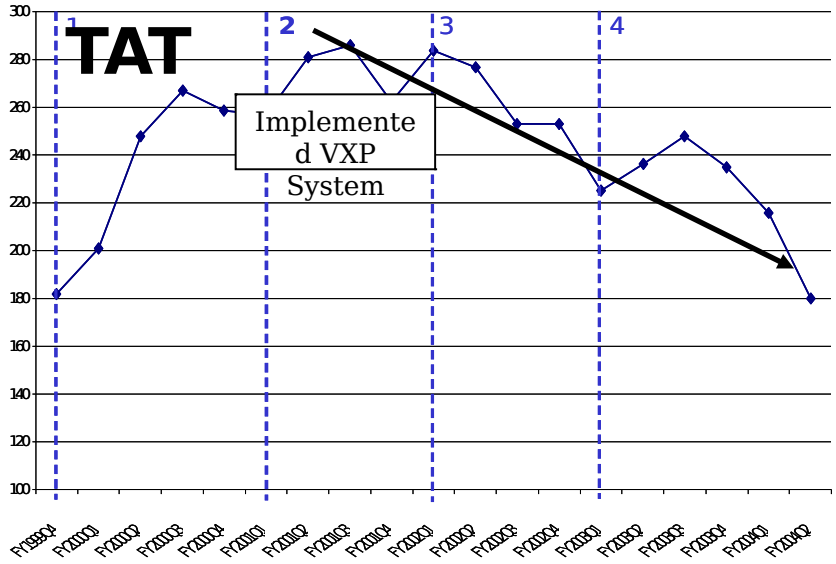


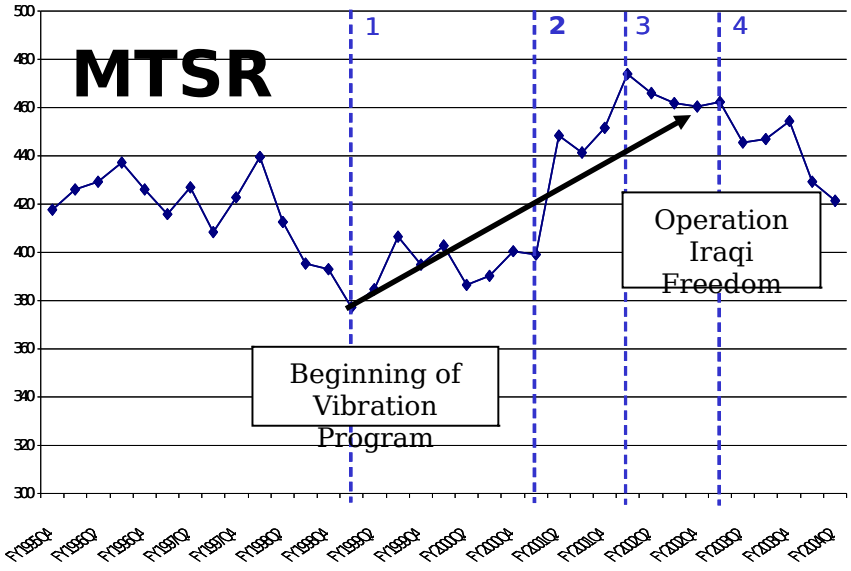


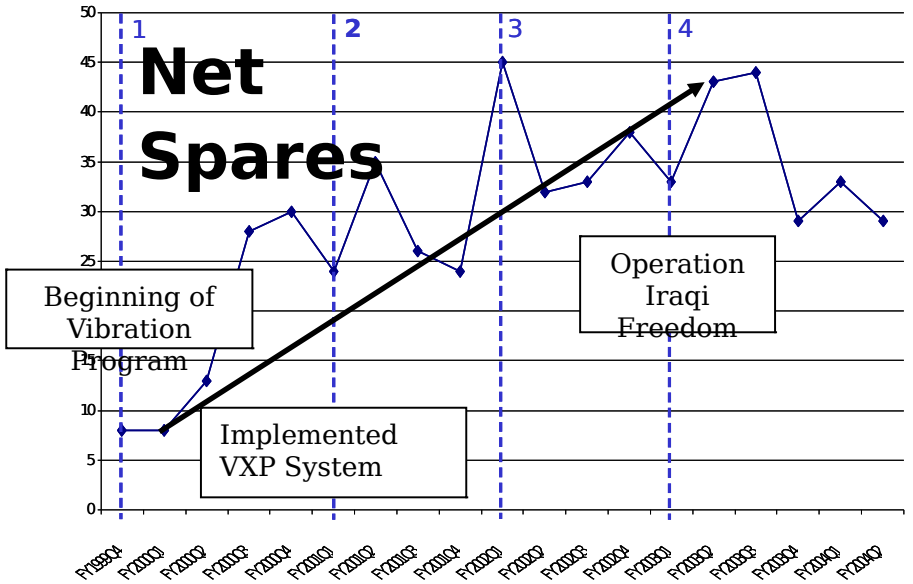
Note concave contour of journal surface
(OD was .052 in undersized as a result of spinning inner race)

Return on Investment

- **Spectral analyzer implementations yield significant benefits**
  - **Increased engine avg. mean time since repair**
  - **Decreased engine turn around time**
  - **Increased average net spares available**







Phase V

On-Board Systems Increase Safety

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Aft Transmission Bearing Failure

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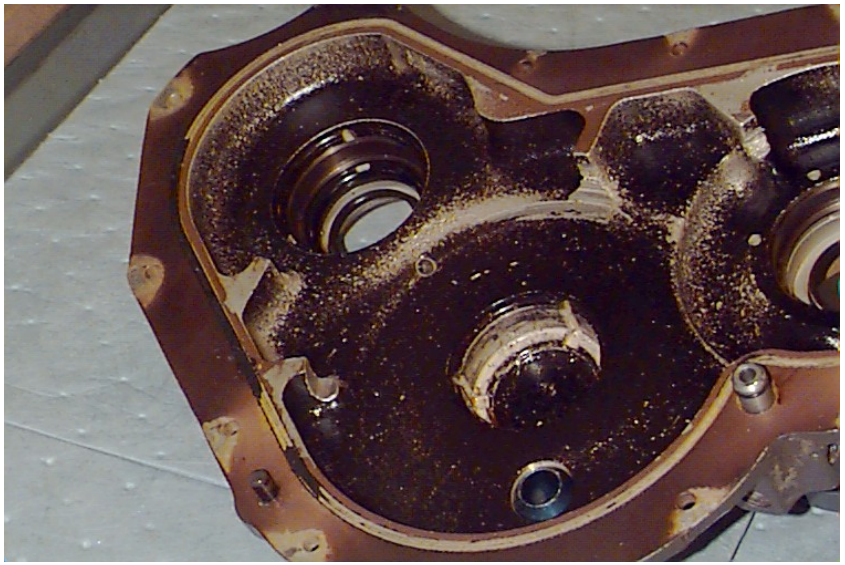
Problem

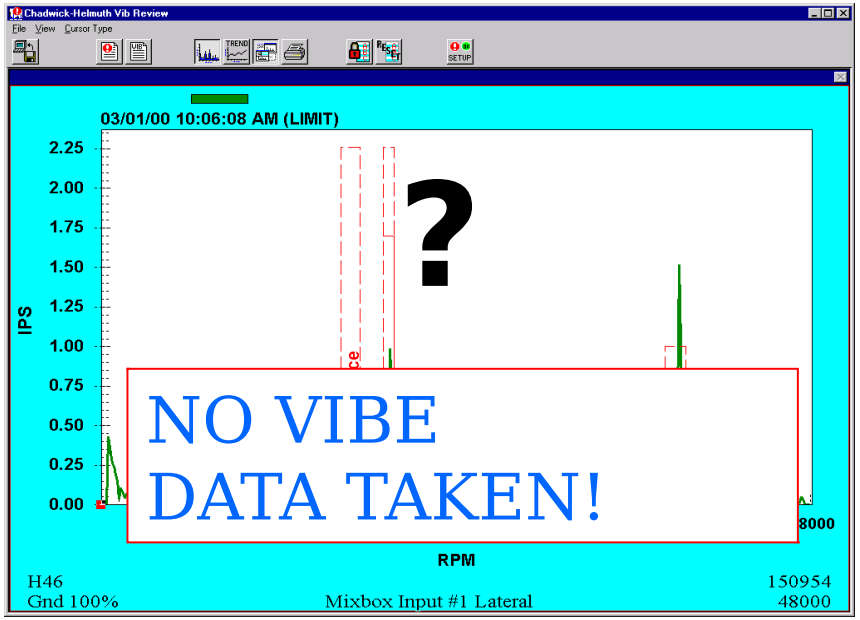
- Aft Transmission Smoking in flight

Findings

- Bearing Failure
- Gearbox failed after bearing failure resulting in sheared lube pump shaft
- Loss of pump caused over temp in flight

- **Resolution**
- 100 Phase check was not performed
- Automated on-board system would have prevented this human induced error





Head Bearing Failure

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Problem

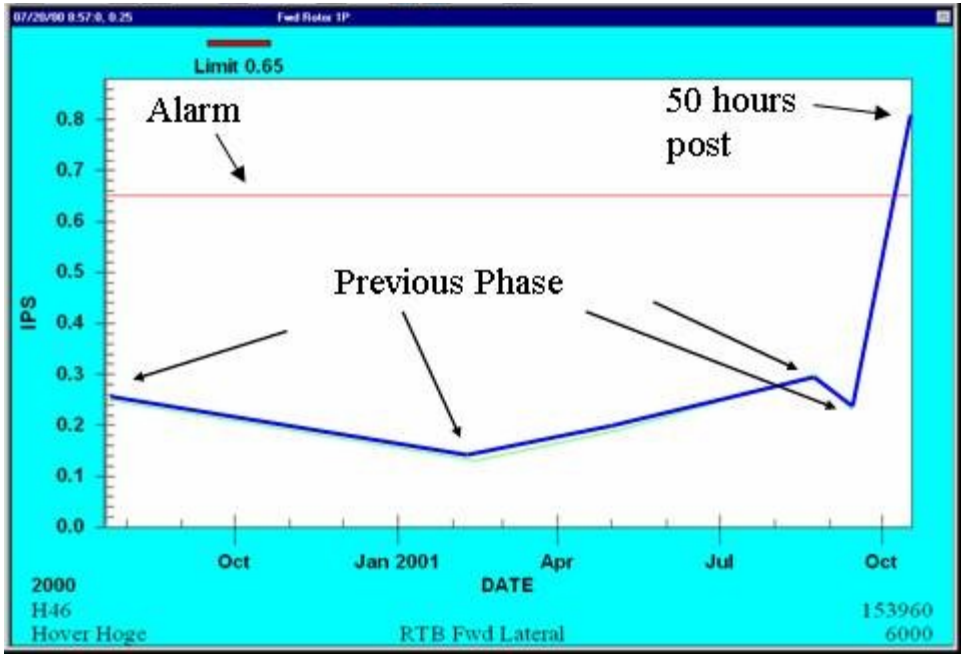
- Post Phase vibration checked and passed
- Significant increases in vibration reported by the crew after only a few hours of flight

Findings

- Repeated vibration checks verified the crew discrepancy
- Vib levels had risen over a short period of time
- Sr. Squadron officer instructed the aircraft to remain in service
- 7 hours later the flight was aborted by the Air Boss – aircraft significantly shaking on deck
- Failed head seal and bearing found
- Oil leakage problem was ignored
- Lack of lubrication led to failure
- Rotor head hub was close to total failure that would have resulted in a complete loss of the aircraft & crew

Resolution

- On-board equipment would have indicated the problem immediately



Phase IV:

On Board System Aircraft Integrated Maintenance System

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Eliminate Support Equipment

- Honeywell Rotor Track and Balance – Model 8500C+
- Vibration Signature Carry – On Accessory Kit
- Howell Instruments Engine Check System – NP600
- Purch , FY 03 – 08)

Logistics Savings Realized

Key Features Derive Solutions

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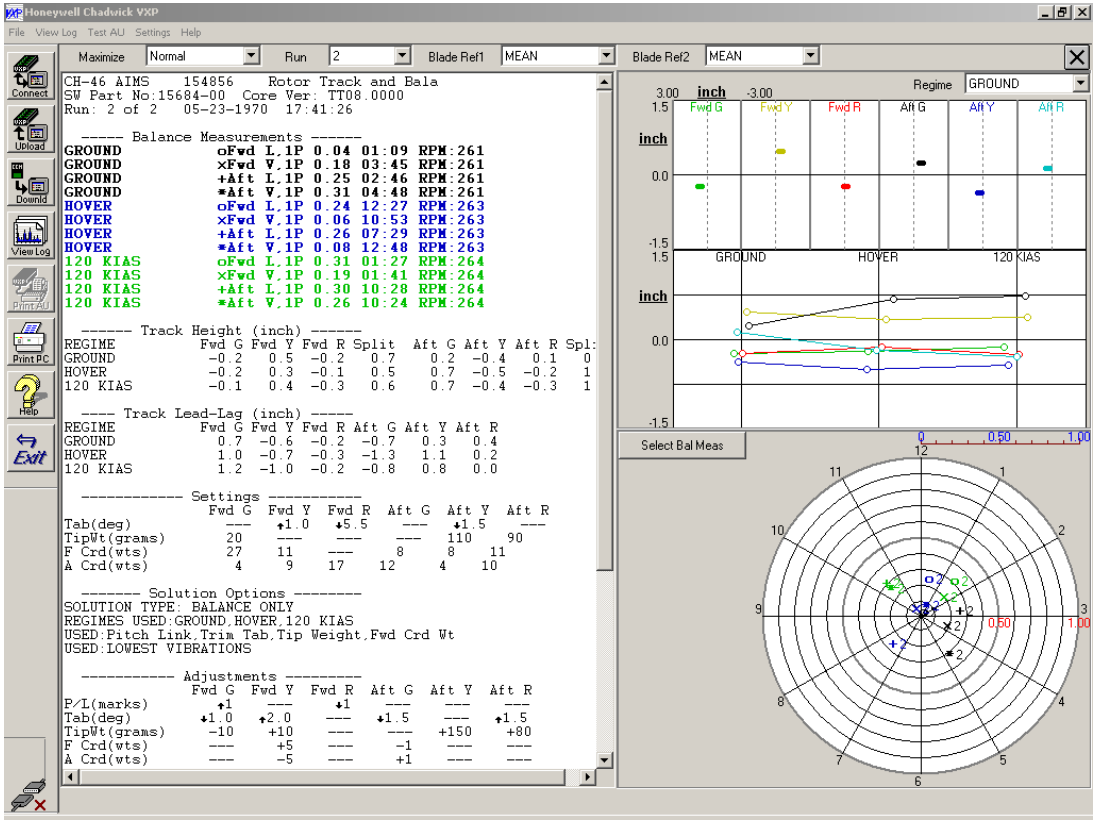
- Rotor Track & Balance
- Periodic Vibration Checks
- Continual Vibration Monitoring
- Engine Performance Checks with automatic nomograph and margin calculations
- Continual Aircraft & Engine Parameter Monitoring
- 1553 Databus interface
- Interface to Control Display Navigational Unit (CDNU) via the 1553 databus
- On Board Go/No Go indications with simple user interface for the aircrew
- Ground Station Software with Go/No Go indications, data archival, data review & analysis

Features with immediate payback

RT&B Displays

- **Polar Plot Display**
- **Track Display**
- **Measurements & Solution Display**
- **Adjustments**



Improves Troubleshooting Capability

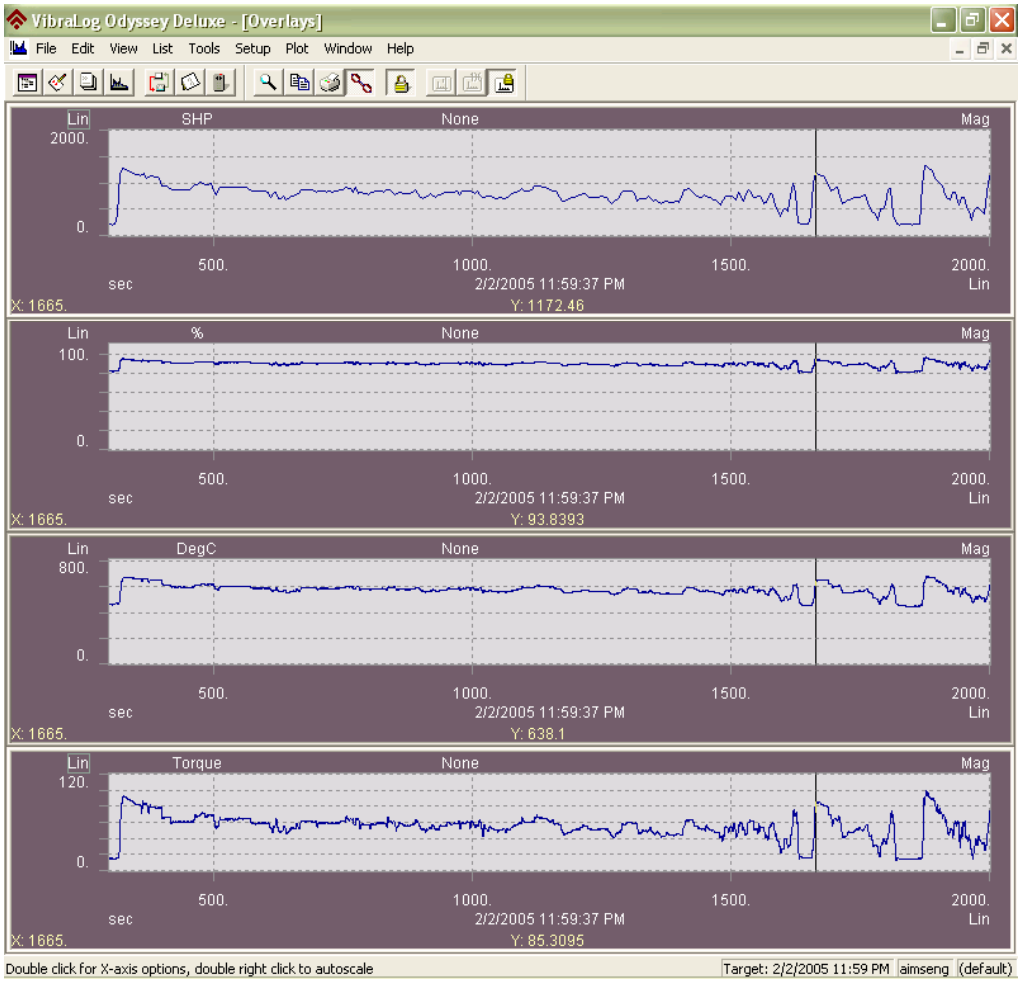
Periodic Checks & Continual Monitoring

- **User definable configurations via Engineering Ground Station Software**
- **Multiple alarming levels, which drive visibility to aircrew**
  - **Master Caution Panel**
  - **On CDNU Display**
  - **On AIMS Acquisition Unit**
  - **On Ground Station**

Immediate Feedback of Alarm Conditions

Periodic Checks & Continual Monitoring

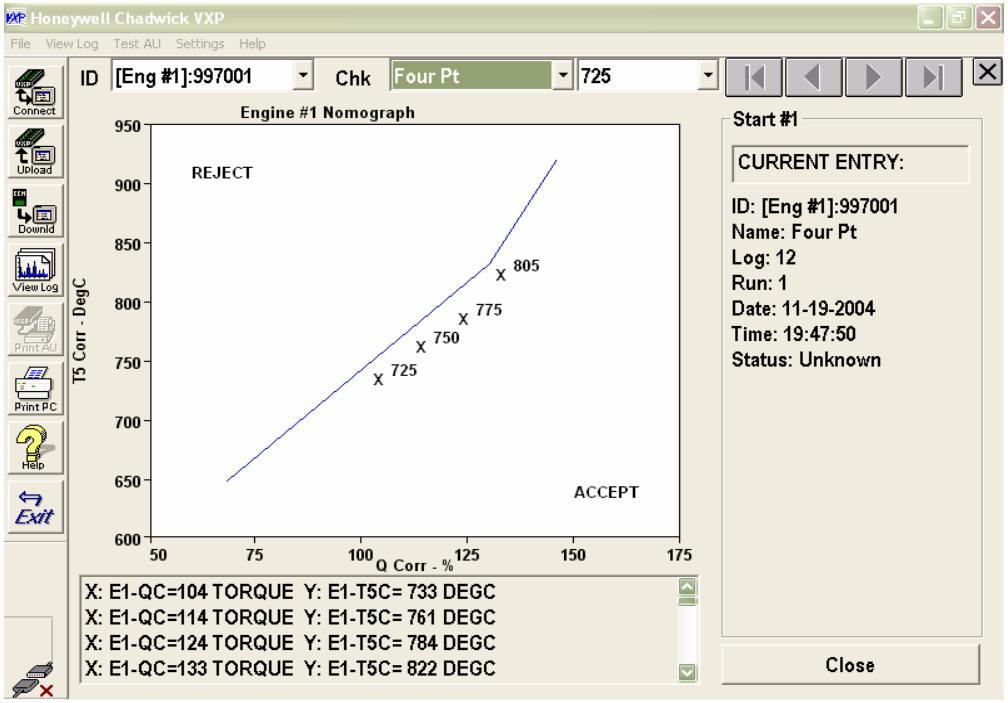
- **Monitors:**
  - **Engine and Drivetrain Vibration Levels**
  - **Overspeeds**
  - **Overtorques**
  - **Overtemperatures**
  - **Chip and Debris Screen States**
  - **Oil Temperature and Pressure**
  - **Engine Performance Margin**
  - **Air Data (OAT, PA, KIAS via 1553B data bus interface)**



Increasing Safety & Reliability

Engine Check Displays

- Engine performance assessed on-board, resulting in immediate feedback of acceptability
- Complete post maintenance check flight engine setup



- Migrating towards fully automated performance margin on the fly
  - Potentially eliminating phase performance check requirement
  - Potentially aiding mission planning efforts

Eliminate Manual Data Entry and Plotting of Data Points

AIMS Savings Realized

- **Annual FCF hours using AIMS will be reduced by 1117 hrs resulting in a savings of $10,938,505 based on FY04 data**
- **FCF setup time; In addition, the time savings will easily surpass 8,000 man hours annually required to set up for FCF's**
- **SE savings: calibration, repair, fleet readiness**
- **AIMS monitor feature has potential to uncover component anomalies, prior to catastrophic failure, inherently save parts and will increase safety**

Features with immediate payback

Conclusion

System Selection Critical

- Automation is good to a point
- No COTS system is 100% ready to go
- Demand control of configurations (routes & limits)
- Control getting drowned in mass amounts of data
- The system must cater to the operator and maintainer
- More is not necessarily better
- Must be simple at end user
- Must inform the operator/maintainer of pending problems or failures
- Grow the system as lessons are learned
- Off site analysis is not practical
- Must conform to new software requirements - NMCI

Understand how your system works for you

Making room for growth

- Advanced Gearbox Diagnostics
- Monitoring of flight controls
- Flight regime recognition for engine performance calculations
- Automation of data management, diagnostics and prognostics
- RT&B “SmartChart” Technology – Tell the maintainer what is wrong with the aircraft

Develop smart solutions

Benefits are tangible

- Significant Cost Savings
- Achieved highest readiness rating
- Engine availability improved
- Back shop procedures improved
- Safety of flight improved

We have realized a significant return

Questions?